# NASA FPGA Needs and Activities

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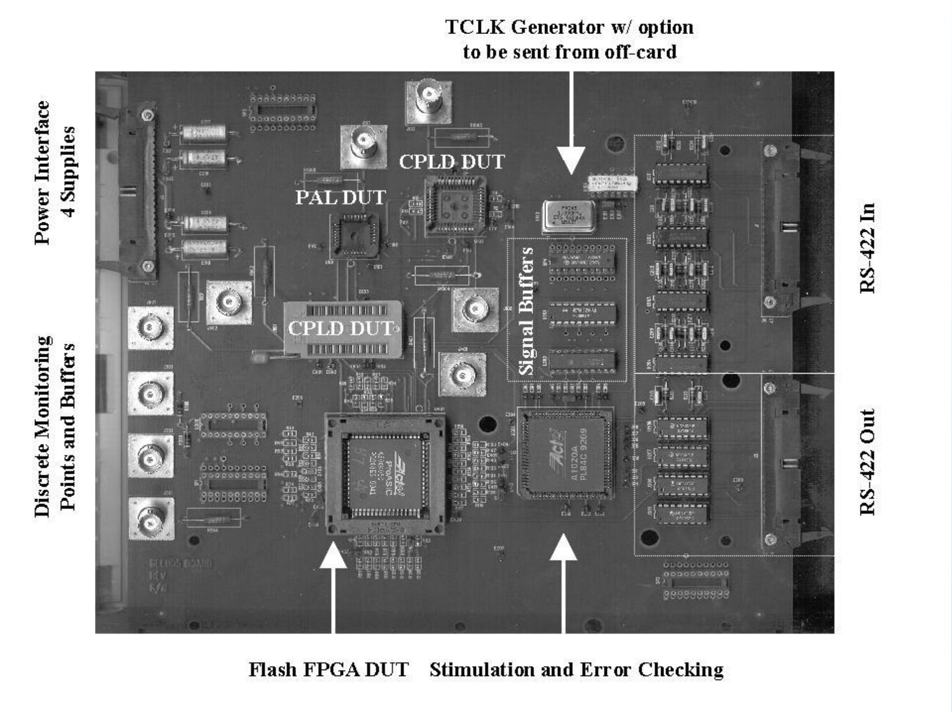
***Unclassified***

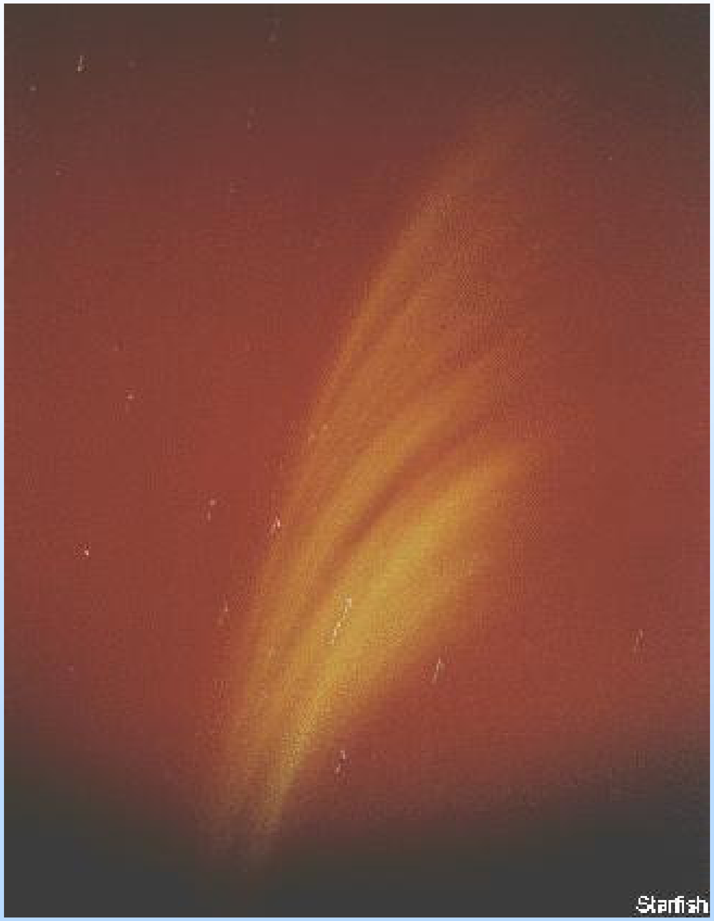
# Outline

- NASA Radiation Environments and Effects of Concern
- NASA Missions
  - Implications to reliability and radiation constraints
- FPGA Trade Space for NASA
- Current Usage Base
- NASA Activities in FPGAs
- FPGA Desirements
- Technical Barriers
- Summary Comments



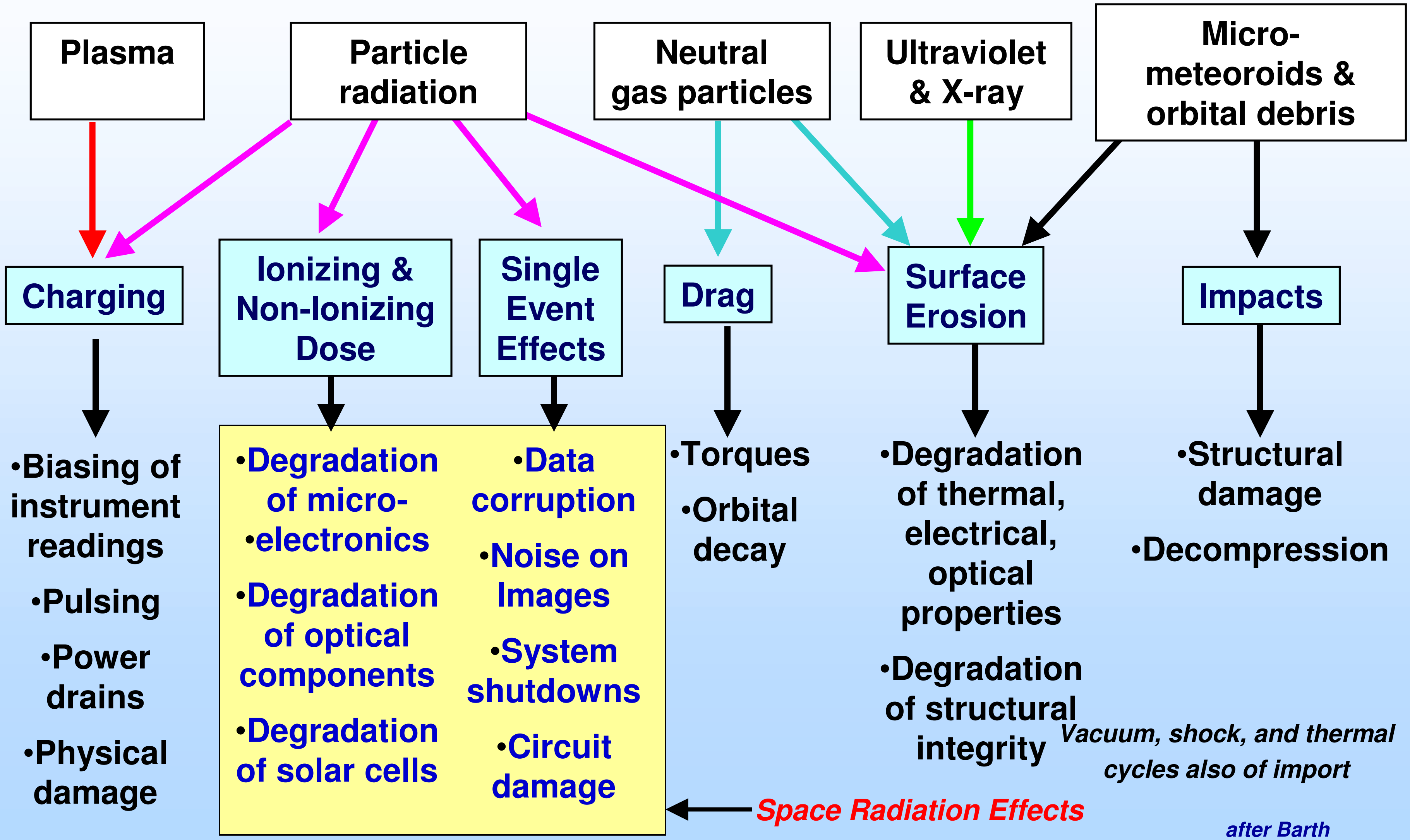

*Typical SEE Test Board for an array of programmable logic device types*

# The Space Radiation Environment



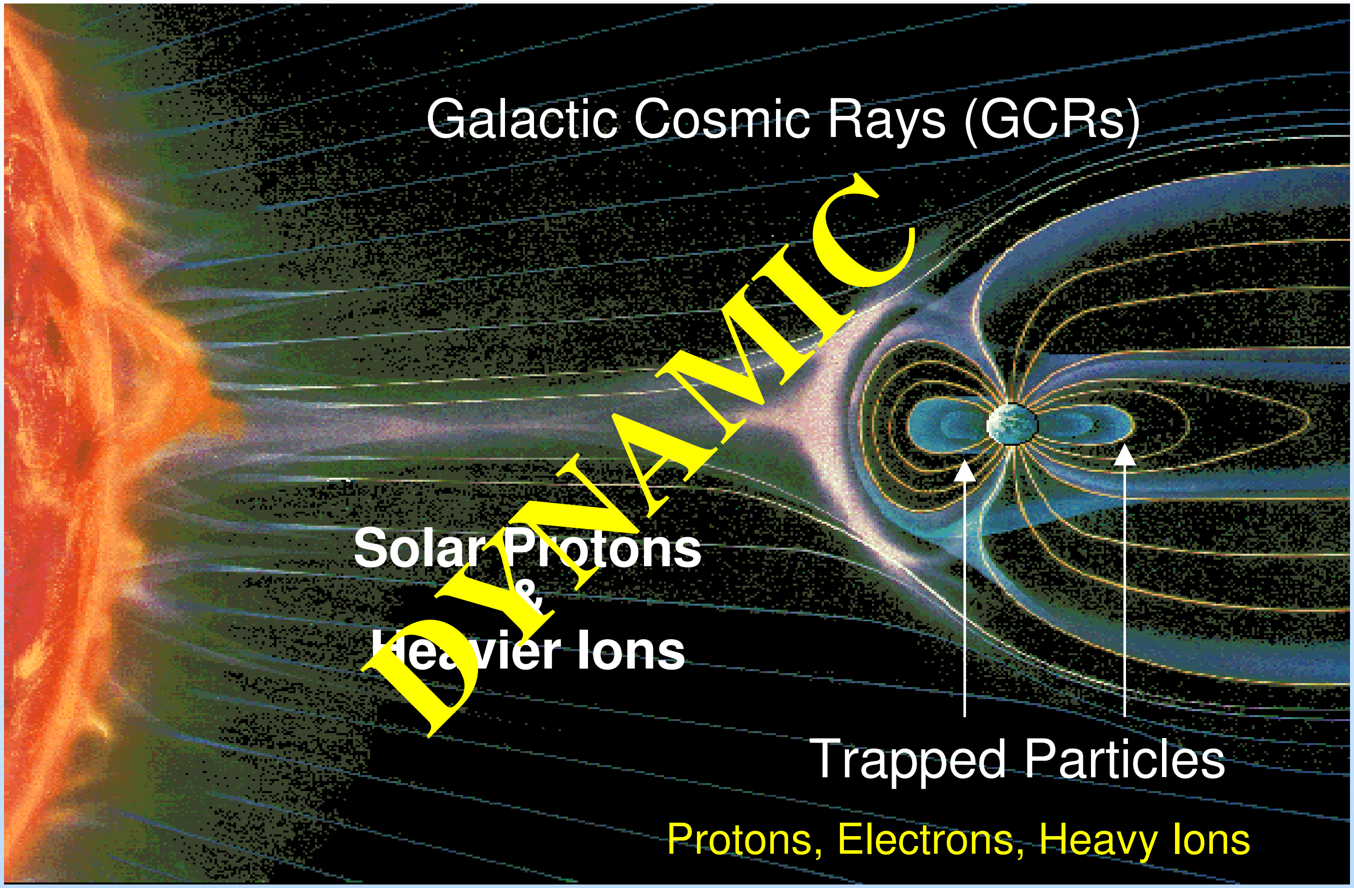

***STARFISH detonation –***
***Nuclear attacks are not considered in this presentation***

# Space Environments and Related Effects



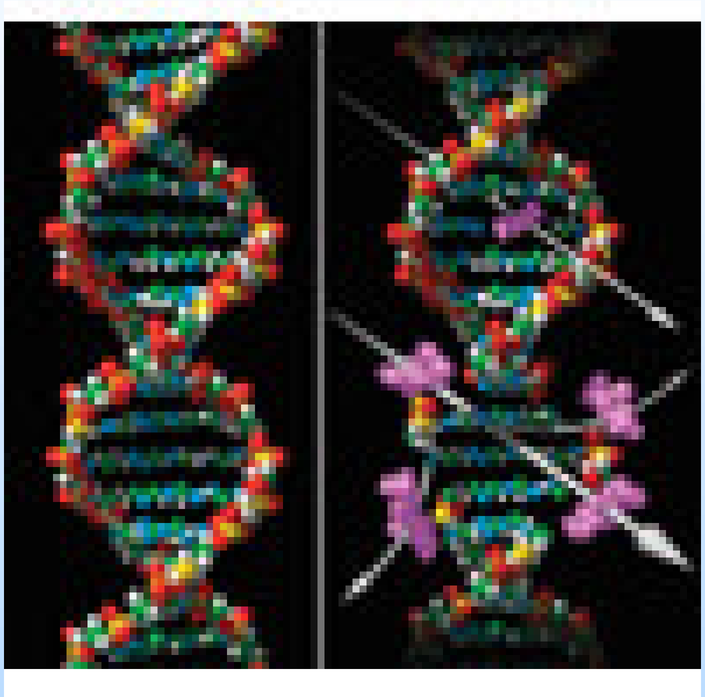
# Space Radiation Environment

*after Nikkei Science, Inc. of Japan, by K. Endo*




***Deep-space missions may also see: neutrons from background or radioisotope thermal generators (RTGs) or other nuclear source Atmosphere and terrestrial may see GCR and secondaries***

# The Effects

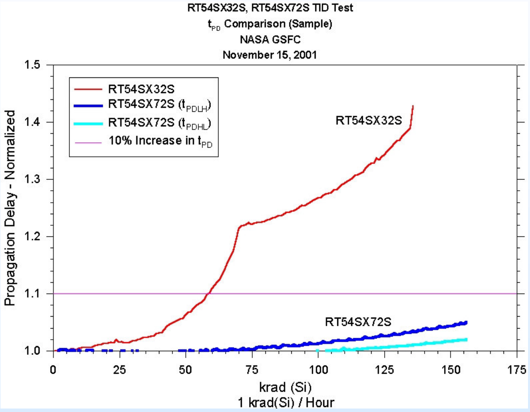


***DNA double helix***
***Pre and Post Irradiation***
***Biological effects are a key concern***
***for lunar and Mars missions***

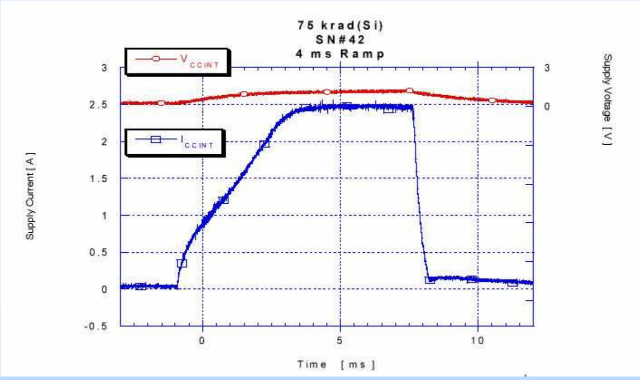
# Total Ionizing Dose (TID)

- **Cumulative long term *ionizing* damage due to protons & electrons**
- **Effects**
  - **Threshold Shifts**
  - **Leakage Current**
  - **Timing Changes**
  - **Startup Transient Current**
  - **Functional Failures**
- **Unit of interest is krad (material)**
- **Can *partially* mitigate with shielding**
  - **Low energy protons**
  - **Electrons**

**TID effects on propagation delay of a 0.25 µm FPGA. Chart shows initial performance and that of a modified COTS rad-tolerant FPGA**




**Increase in startup transient current at 75 krad (Si)**




***TID Effects Many COTS and Modified COTS Programmable Devices***

# Displacement Damage (DD)

- Cumulative long term *non-ionizing* damage due to protons, electrons, and neutrons
- Effects
  - Production of defects which results in device degradation
  - May be similar to TID effects
  - Optocouplers, solar cells, CCDs, linear bipolar devices
- Unit of interest is particle fluence for each energy mapped to test energy
  - Non-ionizing energy loss (NIEL) is one means of discussing
- Shielding has some effect - depends on location of device
  - Reduce significant electron and some proton damage

Not particularly applicable to CMOS microelectronics

# Single Event Effects (SEEs)

- An SEE is caused by a *single charged particle* as it passes through a semiconductor material
  - Heavy ions
    - Direct ionization
  - Protons for sensitive devices
    - Nuclear reactions for standard devices
      - This is similar to the soft error rate (SER) in many respects

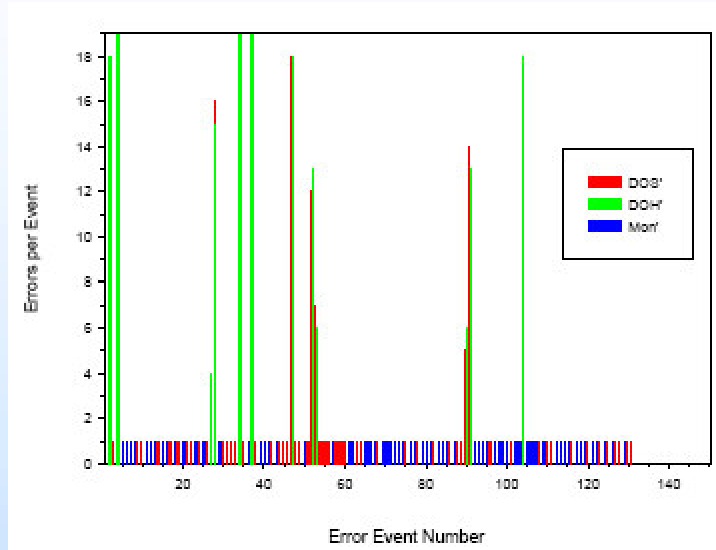
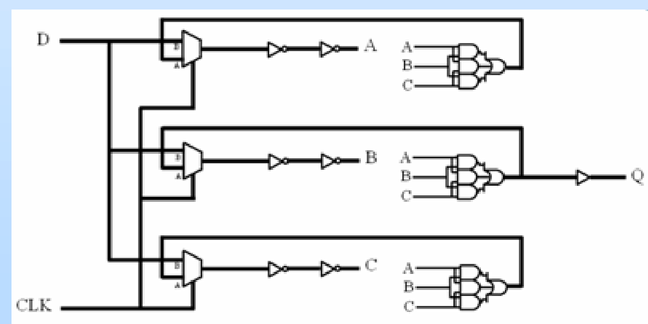



*Chart shows the number of bit errors per event in a shift error from a single SET, in this case a "clock upset." FPGA design was subsequently modified.*

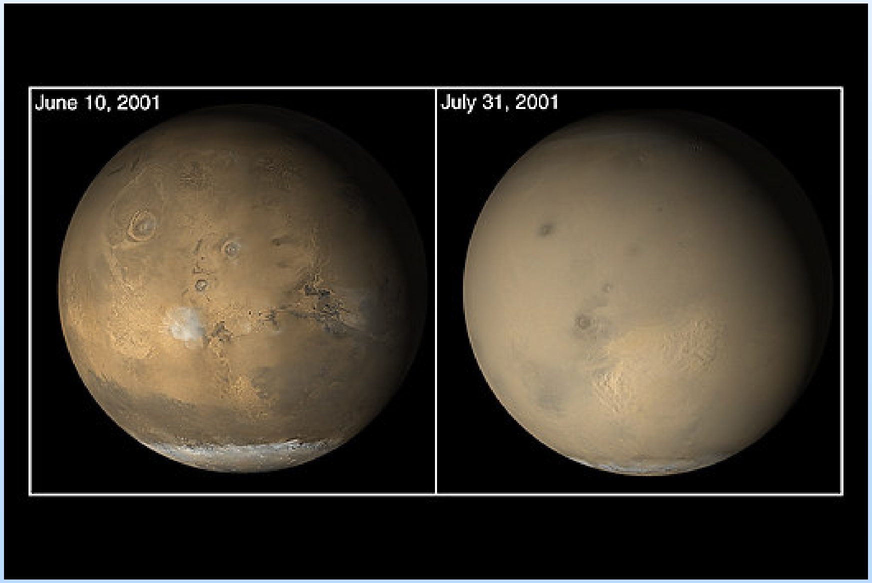
- Effects on electronics
  - If the LET of the particle (or reaction) is greater than the amount of energy or critical charge required, an effect may be seen
    - Soft errors such as upsets (SEUs) or transients (SETs), or
    - Complete loss of control of the device, or
    - Hard (destructive) errors such as latchup (SEL), burnout (SEB), or gate rupture (SEGR)
- Severity of effect is dependent on
  - Type of effect
  - System criticality



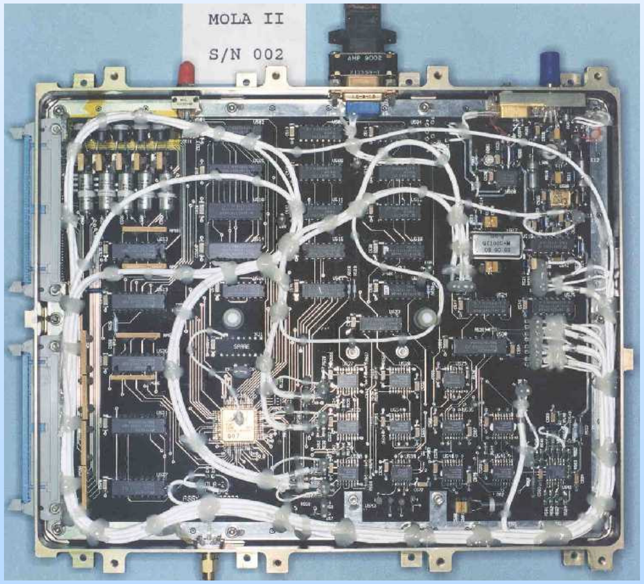

*NASA designed SEU hard latch for FPGAs*

# NASA Missions –
## *A Wide Range of Needs*

- **NASA typically has over 200 missions in some stage of development**
  - **Range from balloon and short-duration low-earth investigations to long-life deep space**
  - **Robotic to Human Presence**
- **Radiation and reliability needs vary commensurately**
  - **5 krad (Si) ≤ TID ≤ 100 krad (Si), for ≥ 95% of all mission**




**Mars Global Surveyor Dust Storms in 2001**




**Use of FPGA in laser altimeter electronics when upgraded from Mars Explorer implementation.**

# Implications of NASA Mix to Radiation Requirements

- **Prior to the new Vision for Space Exploration (re: Moon and Mars)**
  - **>95% of NASA missions required 100 krad (Si) or less for device total ionizing dose (TID) tolerance**
    - **Single Event Effects (SEEs) is a prime driver**
      - **Sensor hardness also a limiting factor**
    - **Many missions could accept risk of anomalies as long as recoverable over time**
- **Implications of the new vision are still TBD for radiation and reliability specifics, however,**
  - **Long-duration missions such as permanent stations on the moon require long-life high-reliability for infrastructure**
    - **Reliability will be the driver for FPGAs**
    - **Diverse technologies for manned Mars missions**
    - **Human presence requires conservative approaches to reliability and begets Radiation Protection Strategies**
      - ***Drives stricter radiation tolerance requirements and fault tolerant architectures***
  - **Nuclear power/propulsion changes radiation issues (TID and displacement damage)**

**Lunar footprint**
***Courtesy of NASA archives (Note some Apollo hardware is still functioning on the Moon and used by scientists)***

# NASA Trade Space for FPGA Usage

- **NASA tends to build one-of-a-kind instruments (or at best, a few copies) and spacecraft**
  - ASICs are used primarily in NASA when:
    - Performance driven: speed/size of circuit drive the need
    - Mixed-signal functions required
    - Repetitive usage of ASIC: applications that can utilize thousands of copies of the same circuit
      - We've seen up to 15,000 of the same ASIC used in a science instrument!
      - Other ASICs used in those role offer "generic" functions such as SpaceLAN, SpaceWire, Space Ethernet
  - FPGAs are used by NASA for
    - Standard logic replacement
    - Embedding microprocessors, memory, controllers, communications devices, in a path towards "systems on a chip."
  - Estimate of NASA ASIC vs. FPGA Usage
    - NASA uses >> 10 FPGA designs for every ASIC design
    - PLD Survey currently underway

# NASA Applications for FPGAs

- In essence, electronic designs may be classed into two categories for NASA space, each has critical and non-critical sections:
  - Control/Spacecraft
  - Science/Instrument
- Control applications are the heartbeat of the space system
  - Reliability, minimal downtime (re: science data loss), failure-free, etc are the drivers
  - Control applications include explosive devices
  - Without an operating spacecraft, the best instrument is useless
- Science applications are the more performance driven
  - When you are measuring the universe, you need lots of resolution, bandwidth, and memory throughput
  - We can lose some data, but we can't lose a mission
    - Tolerance is getting stricter with longer staring times, etc for instruments
- Each will be discussed with type of FPGA NASA considers

# Control Applications and FPGA NASA Needs

- Application: Control (ex., attitude control)
- General Needs:
  - High-reliability
  - Radiation hardness (system must be bullet-proof)
  - Fail-safe
- Device characteristics
  - Small to medium size
    - $10^4$ to $10^5$ gates
  - Operating speed ranges from low to high ( < 200 MHz system clock)
  - One-time programmable (OTP) or reprogrammable
    - Reprogrammable is often preferred for schedule and flexibility, but can complicate system design (SEU tolerance/mitigation, etc…)
  - Low to moderate power
- Some NASA systems are using of reprogrammable devices for control
  - Extreme care needed to prevent inadvertent deployments or other critical events

# Science Applications and FPGA NASA Needs

- Application: Science (ex., image data throughput)
- General Needs:
  - Medium to High performance
  - Radiation tolerance (acceptable data losses)
  - Fail-safe
- Device characteristics
  - $10^4$ to $10^6$ gates
  - Operating speeds range from low to high ( some > 200 MHz)
  - Reprogrammable
    - Preferred for flexibility to adapt algorithms for on-board processing of science data
  - Low-power desired
    - Conflicts with larger device sizes
- Most NASA systems are still using OTP devices for radiation tolerance reasons

# Current NASA FPGA Usage

- **Primary NASA usage and plans:**
  - Actel for OTP
  - Xilinx for SEU-based reprogrammable
  - Aeroflex coming into market
    - Licensed designs and OTP technology from Quicklogic
  - Honeywell Rad-Hard Reconfigurable FPGA (RHrFPGA)
    - Sold as board-level product
    - NASA a prime funding source
    - NASA supported radiation evaluation
- **Other examples:**
  - Altera (Space Shuttle, ISS) in communications applications
  - Lucent used in GPS receivers/processors
  - PLD's used in X-vehicles (planes)

# NASA R&D Activities on FPGAs

- Reliability and Radiation Evaluation
  - Actel 54RTSX-S Programmed Antifuse Investigation
    - Rich Katz, NASA Office of Logic Design (OLD)
    - See http://klabs.org for details
  - Radiation evaluation board in design for Aeroflex FPGAs
  - Xilinx Virtex-II Pro
    - Funded by Missile Defense Agency
    - Consortia with AFRL, NAVSEA
    - SEE test scheduled for Aug 16$^{th}$
    - JPL represents NASA on Xilinx SEE Consortia
  - See http://klabs.org for other recent radiation efforts
- Architecture
  - Multiple efforts looking at COTS reprogrammable FPGAs
    - System architectures funded under former NASA Code R MSMT
    - MDA funding of architecture work on Xilinx Virtex-II Pro
- Military and Aerospace Programmable Logic Devices International Conference (MAPLD)
  - September 8-10, 2004 in Washington, DC
  - Hosted by NASA Office of Logic Design (R. Katz)
    - http://klabs.org/mapld04
    - richard.b.katz@nasa.gov

# NASA Desirements

- High Reliability: ≤ 10 FITs
- Non-volatile
- Reprogrammable, Unlimited Times, High-Speed, Device Sections
- Rad-tolerant (configuration should be radiation-hard)
  - ≥ 100 krad (Si)
  - ≥ 75 MeV-cm$^2$/mg SEL
  - ≥ 75 MeV-cm$^2$/mg Damage
  - ≥ 40 MeV-cm$^2$/mg Configuration Memory and Control Registers $SEU_{TH}$
  - ≥ 40 MeV-cm$^2$/mg SEU – Control Applications
  - ≥ 15 MeV-cm$^2$/mg SEU – Science Data Processing Applications
- $10^5$ to $10^6$ Gates
- High-speed of Operation
- On-chip, dual-port, block memories
- Multiple on-chip processors with facilities for checkpointing, restarting, comparing, and sparing
- I/O Modules tolerant of different voltages and standards. This is critical as other devices on-card will be of varying technologies (commercial applications tend to not have this problem to a large extent).
- Support for high-speed arithmetic (e.g., fast carry chains, multipliers, etc.)
- Simple architecture: Complexity breeds design errors and makes validation efforts "challenging."
- Reliable and Accurate Software Tools – e.g. Static Timing Analyzers
  - Guarantee both minimum and maximum bounds
  - Min/Max Clock Skew Analysis
  - Account for radiation and life effects
- Commercially compatible architecture
  - Use standard tool chain
  - Available "intellectual property"
  - Large designer experience base

# Technical Issues

- **Reliability: MEC SX-A and SX-S Programmed Antifuse**
  - Currently undergoing intense study, evaluation, and modifications (NASA OLD/NESC, Aerospace Corp./DoD)
  - SX-SU (UMC) alternative is also being evaluated in parallel
  - SX-A used in many military weapons
- **Radiation**
  - Commercial FLASH is horrible
  - Commercial CMOS is VERY soft to SEU and may have destructive issues
    - Scrubbing, reconfiguration are okay, but not proven, and do not cover all of memory
- **Signal Integrity**
  - Programmable drive strength, slew, and impedance
  - Improved IBIS models
- **Packaging**
  - >1000 pin packages with no simple space qualification path
  - Interconnects
  - Ground bounce and $V_{DD}$ sag
    - Additional power and ground pins
    - Capacitors internal to the package

# Comments on FPGA Radiation Needs

- NASA recommends investments in three areas
  - Bulletproof device for control application
    - Reliability
    - Radiation
    - Verifiable Designs
  - Radiation-tolerant reprogrammable device for on-board processing and non-critical control applications
    - Compatible with commercial design tool chain
    - Goal: No radiation mitigation required
      - Supports mitigation strategies if necessary
  - Coordinated interagency evaluation program for COTS FPGAs
    - Radiation - Test and mitigation
    - Reliability – Test and detailed evaluation of vendor qualification
    - Intellectual Property – Library of Government-developed IP

**For additional information on NASA FPGA Efforts**

**http://klabs.org**